US009309722B2

(12) United States Patent
Kibsgaard et al.

(10) Patent No.: US 9,309,722 B2
(45) Date of Patent: Apr. 12, 2016

(54) **OIL OPERATED ROTARY STEERABLE SYSTEM**

(75) Inventors: **Paal Kibsgaard**, Houston, TX (US); **Geoffrey C. Downton**, Gloucestershire (GB)

(73) Assignee: **Schlumberger Technology Corporation**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 589 days.

(21) Appl. No.: **13/699,617**

(22) PCT Filed: **Jun. 17, 2011**

(86) PCT No.: **PCT/US2011/040893**
§ 371 (c)(1), (2), (4) Date: **Jan. 22, 2013**

(87) PCT Pub. No.: **WO2011/160027**
PCT Pub. Date: **Dec. 22, 2011**

(65) **Prior Publication Data**

US 2013/0112483 A1 May 9, 2013

Related U.S. Application Data

(60) Provisional application No. 61/356,442, filed on Jun. 18, 2010.

(51) **Int. Cl.**
E21B 7/06 (2006.01)
E21B 7/10 (2006.01)

(52) **U.S. Cl.**
CPC . *E21B 7/06* (2013.01); *E21B 7/067* (2013.01); *E21B 7/10* (2013.01)

(58) **Field of Classification Search**
CPC E21B 17/1014; E21B 7/06; E21B 7/067; E21B 7/10
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,548,282	A *	10/1985	Hurtz et al.	....	175/61
6,109,372	A *	8/2000	Dorel et al.	....	175/61
2003/0127252	A1	7/2003	Downton et al.		
2006/0243487	A1 *	11/2006	Turner et al.	....	175/26
2006/0249287	A1 *	11/2006	Downton et al.	....	166/250.1
2007/0235227	A1 *	10/2007	Kirkhope et al.	....	175/73
2009/0032302	A1	2/2009	Downton et al.		
2009/0223717	A1 *	9/2009	Eppink	....	175/25

FOREIGN PATENT DOCUMENTS

WO 2009/002996 12/2008

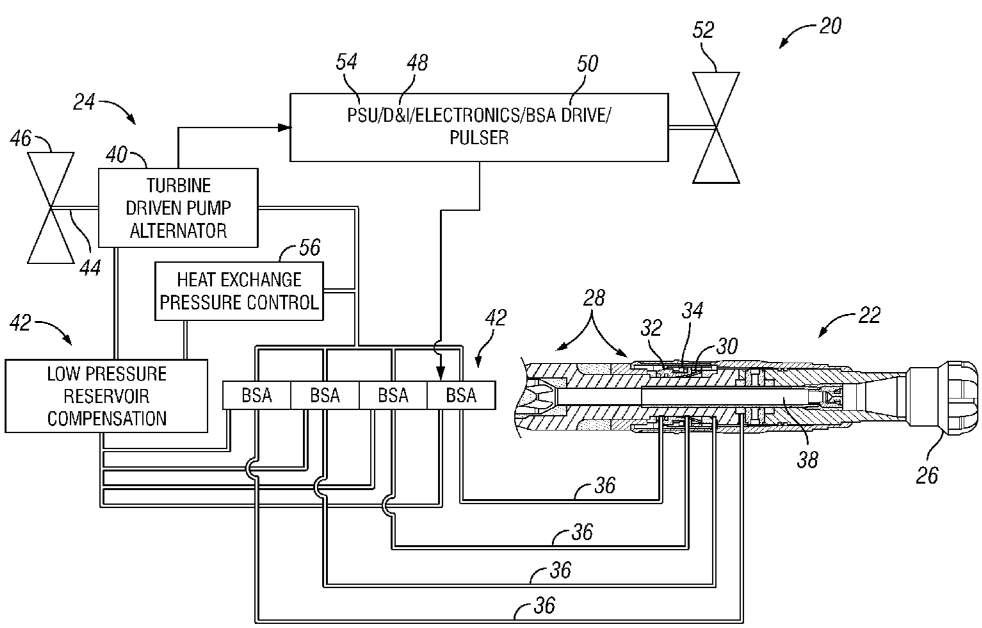
* cited by examiner

Primary Examiner — Shane Bomar
Assistant Examiner — Christopher Sebesta

(57) **ABSTRACT**

A technique facilitates steering of rotary steerable systems when conducting directional drilling operations. A rotary steerable system is combined with a pressurized oil system which delivers oil to a piston actuated mechanism. The pressurized oil provides precise, long-lasting control over the orientation of the bottom hole assembly and the drill bit to facilitate directional drilling of boreholes through subterranean formations.

11 Claims, 2 Drawing Sheets



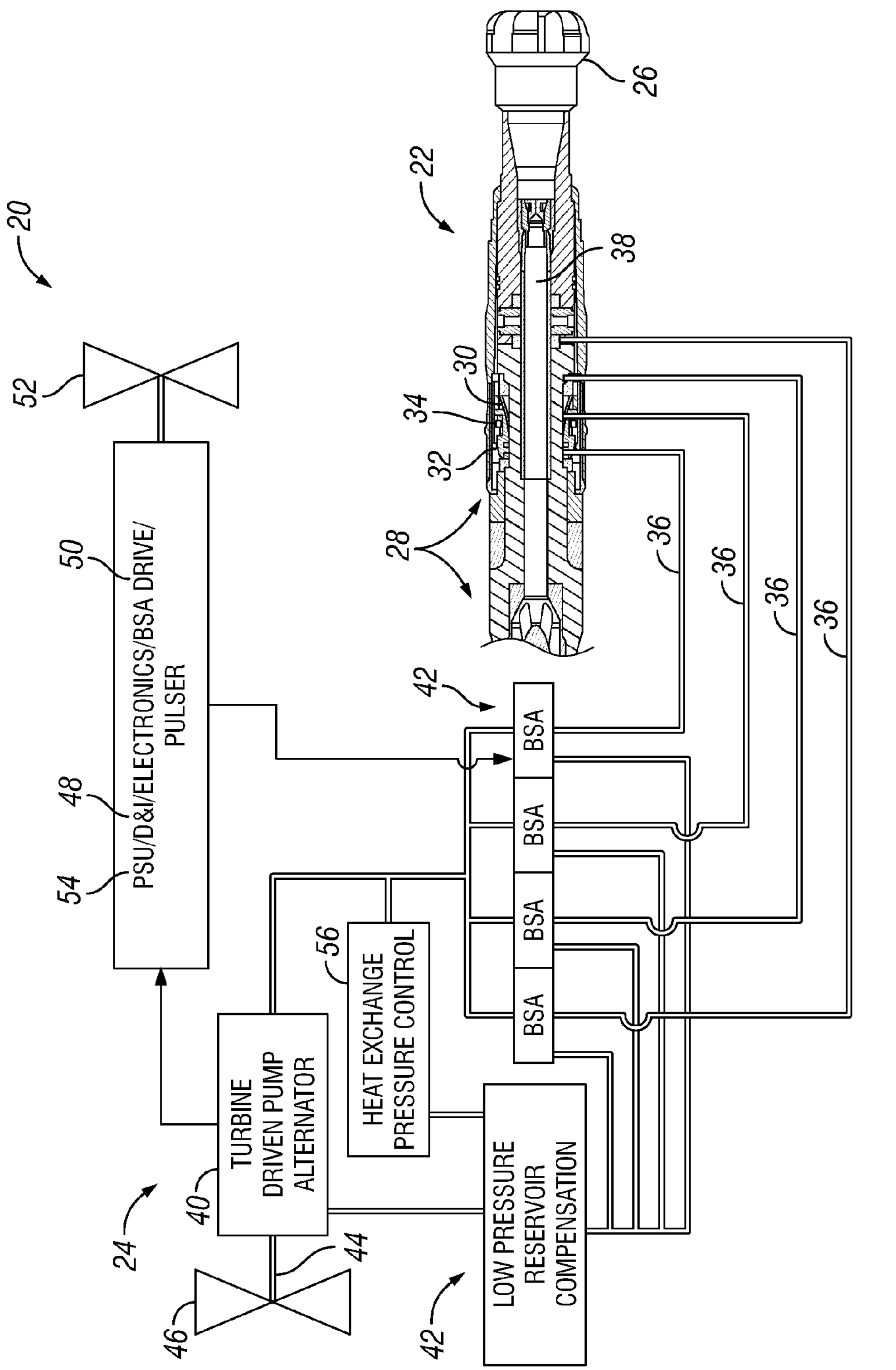

20
22
26
38
30
34
32
28
36
36
36
36
52
50
48
54
PSU/D&I/ELECTRONICS/BSA DRIVE/
PULSER
42
BSA
BSA
BSA
BSA
56
HEAT EXCHANGE
PRESSURE CONTROL
TURBINE
DRIVEN PUMP
ALTERNATOR
40
24
44
46
42
LOW PRESSURE
RESERVOIR
COMPENSATION

FIG. 1

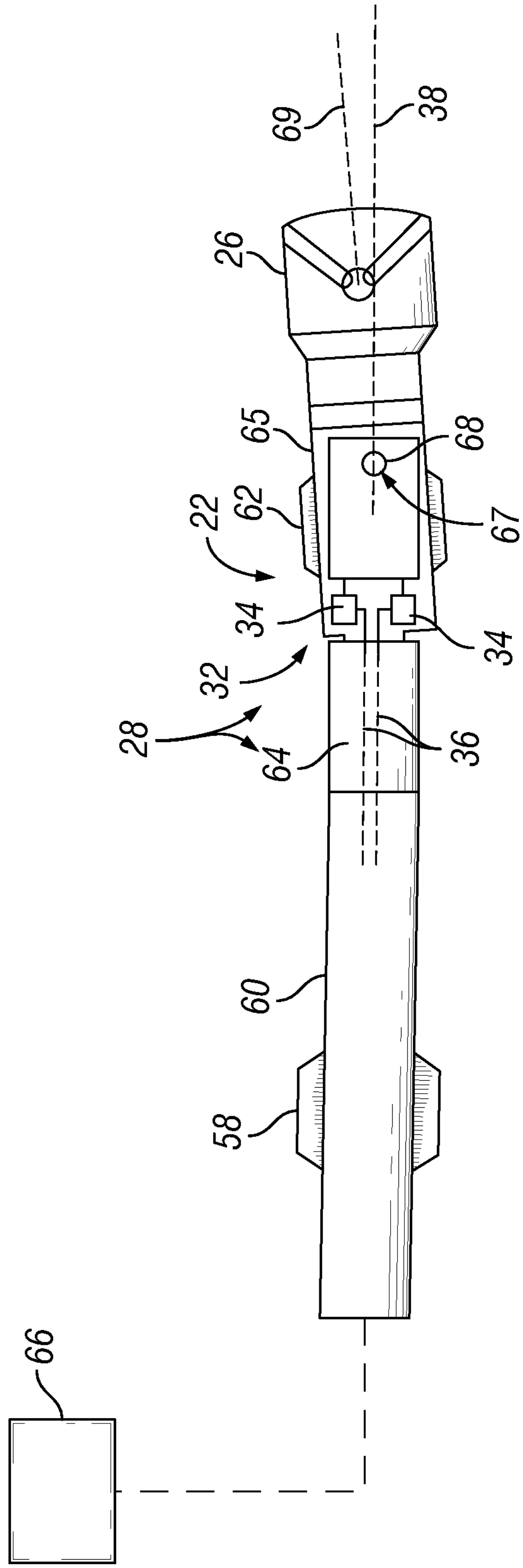


FIG. 2

OIL OPERATED ROTARY STEERABLE SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

The present document is based on and claims priority to U.S. Provisional Application Ser. No. 61/356,442, filed Jun. 18, 2010, incorporated herein by reference.

BACKGROUND

Rotary steerable drilling systems for drilling deviated boreholes into the earth are generally classified either as point-the-bit systems or push-the-bit systems. In point-the-bit systems, the axis of rotation of the drill bit is deviated from the local axis of the bottom hole assembly in the general direction of the new portion of the hole being drilled. The borehole is propagated according to customary three-point geometry defined by upper and lower stabilizer touch points and the drill bit. The angle of deviation of the drill bit axis coupled with a finite distance between the drill bit and a lower stabilizer results in a non-collinear condition required for a curve to be generated. In this type of system, the drill bit tends to have less sideways cutting because the bit axis is continually rotated in the direction of the curved borehole.

In push-the-bit rotary steerable systems, there is usually no specially identified mechanism to deviate the bit axis from the local bottom hole assembly axis. Instead, the requisite non-collinear condition is achieved when either upper or lower stabilizers are used to apply an eccentric force or displacement in a direction oriented with respect to the direction of borehole propagation. Steering is again achieved by creating non co-linearity between the drill bit and at least two other touch points. In this type of system, the drill bit is required to cut sideways to generate the desired, curved borehole.

In many of these rotary steerable systems, pistons may be used to create force against a borehole wall or to cause angular displacement of one steerable system component with respect to another to cause the drill bit to move in the desired direction of deviation. The pistons are deployed in a piston actuated mechanism and forced to their desired displacement to achieve the directional control. The pistons are manipulated via drilling mud pumped down through the bottom hole assembly. However, such systems may be subjected to internal wear from the flowing mud and also may be limited with respect to the forces which may be applied to steer the drill bit.

SUMMARY

In general, the present invention provides a technique which facilitates steering of steerable systems when conducting directional drilling operations. A directional drilling system (e.g. a rotary steerable system) is preferably combined with a pressurized oil system which delivers oil to a piston actuated mechanism. The pressurized oil provides precise, long-lasting control over the orientation of the bottom hole assembly and the drill bit to facilitate directional drilling of boreholes through subterranean formations.

BRIEF DESCRIPTION OF THE DRAWINGS

Certain embodiments of the invention will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements, and:

FIG. **1** is a schematic illustration of a rotary steerable system coupled with a pressurized oil system, according to an embodiment of the present invention; and

FIG. **2** is a schematic example of one type of bottom hole assembly and rotary steerable system incorporating pistons which are controlled by the pressurized oil system, according to an embodiment of the present invention.

DETAILED DESCRIPTION

In the following description, numerous details are set forth to provide an understanding of the present invention. However, it will be understood by those of ordinary skill in the art that the present invention may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible.

The disclosure herein generally relates to a steering system for directional drilling. A bottom hole assembly incorporates a rotary steerable system having a piston actuated mechanism. However, the piston actuated mechanism is controlled by pressurized oil supplied from a pressurized oil system rather than being controlled by flowing drilling mud. The flow of oil to pistons of the piston actuated mechanism is controlled by a valve system. The valve system allows the pressurized oil to be ported to the pistons of the rotary steerable system to, for example, point the bit in the desired steering direction. The force required to manage the reactive forces from weight on bit (WOB), bottom hole assembly (BHA) mass and other drilling loads is provided by the pressure differential between the annulus and the pressurized oil acting across the piston area of the pistons. The separate pressurized oil system may be used with, for example, point-the-bit type systems, push-the-bit systems, or other types of steerable drilling systems.

Referring generally to FIG. **1**, an embodiment of a drilling system **20** is illustrated. In this embodiment, drilling system **20** comprises a bottom hole assembly **22** coupled with a pressurized oil system **24**. The bottom hole assembly **22** comprises a drill bit **26** connected to a rotary steerable system **28** having a steering section **30** which is selectively manipulated via a piston actuated mechanism **32** having a plurality of pistons **34**. Pressurized oil system **24** is employed to route pressurized oil to piston actuated mechanism **32** and to selected pistons **34** via oil supply lines **36**. The pressurized oil is used to move specific pistons **34** which changes the orientation of the drill bit **26**, e.g. changes the drilling axis orientation, with respect to the longitudinal axis **38** of the bottom hole assembly **22**. For example, the pistons **34** may be employed to control at least one of the directional bias and the axial orientation of the drill bit **26**. The pistons **34** may be arranged, for example, to point the drill bit **26** or to push the drill bit **26**. By way of specific example, the drilling system **20** utilizes rotary steerable system **28** which rotates with the plurality of pistons/actuators **34**. Additionally, the rotary steerable system **28** may be used in conjunction with stabilizers, such as non-rotating stabilizers.

Pressurized oil system **24** may comprise an oil pump **40** which pressurizes the oil supplied through oil supply lines **36** for controlling the drilling orientation of the rotary steerable system **28**. The pressurized oil from pump **40** may be routed through a valve system **42** used to control the flow and pressure of the oil supplied to pistons **34** of rotary steerable system **28** and piston actuated mechanism **32**.

In the embodiment illustrated, oil pump **40** is driven by a shaft **44** which, in turn, may be driven directly by flowing drilling mud flowing through a turbine **46** or other device designed to power oil pump **40**. Alternatively, the oil pump **40** may be powered by an electric motor **48**. In the case of an electric motor, electrical power may be provided to motor **48** by an alternator **50**. By way of example, the alternator **50** may be driven by drilling mud, e.g. driven by drilling mud via a mud turbine or mud pump (PDM) **52**. In the embodiment employing electric motor **44**, a speed control system **54** may be implemented to maintain a constant pump pressure. In the embodiment in which pump **40** is a direct mud driven pump, the pressure may be maintained by an internal pressure relief valve **56**. It should be noted that electrical power may be supplied to motor **48** from other sources, e.g. from a surface supply coupled to electric motor **48** via cable or other conductors routed downhole.

The motive fluid for steering rotary steerable system **28**, e.g. oil supplied through oil supply lines **36**, works between a high-pressure source and a low-pressure reservoir. The low-pressure reservoir may be pressure balanced with the pressure internal to the drill string. The power required to provide the cyclic steering forces as the drill string rotates often requires a mechanical source of energy of several kWatts. For example, 5000 pounds acting over 0.25 square inches requires 141 joules at four times a second (240 rpm)–mechanical power of 1700 Watts assuming there is no energy recycling/storage.

The valve system **42** employs valves to control the flow of pressurized oil into/out of the pistons **34**, and those valves may comprise bistable actuators (low energy fluid flow switches) or piezo restrictive actuator valves. As an alternative, the valve system **42** may employ a rotary valve format, such as the rotary valve format used in the PowerDrive rotary steerable system available from Schlumberger Corporation. In either case, the system is designed to track the local gravity vector to enable the system to determine which valves are to be activated to achieve the required steering response taking into account the various tool face offset effects that exist due to friction, bit response, bottom hole assembly load, formation tendencies, and other potential factors. The gravity and valve data may be provided by suitable sensors. However, other types of valves and sensor systems may be employed in pressurized oil system **24** to control the flow of pressurized oil.

By using the separate pressurized oil system **24** to control the orientation of rotary steerable system **28**, less internal wear results which enables extended runtimes and a reduction in tools for each drilling job. The pressurized oil system also is amenable to higher pressure which, in turn, enables actuation by smaller pistons **34**, thereby providing more flexibility with respect to both packaging and actuation. The pressurized oil system **24** further enables use of higher forces while eliminating the coupling of actuation force and flow rate of the drilling mud. Additionally, the system **20** no longer requires relatively high bit drop pressures. The pressurized oil also can be combined with oil needed for other drilling systems. Depending on the specific application, the pressurized oil system **24** may be located in whole or in part downhole along the drill string. For example, the oil pump **40** and the valve system **42** may be located anywhere in the bottom hole assembly. The rotary steerable system **28** and the pressurized oil system are designed so that the pistons **34** can be actuated independently to achieve a straight ahead steering. Additionally, the design of the system enables modulation of the piston displacement and forces in synchronism with the phase of drill string rotation to achieve intermediate steering curvatures.

The pressurized oil system **24** may be used in combination with a variety of bottom hole assemblies **22** and rotary steerable systems **28**. However, one example of a suitable bottom hole assembly is illustrated in FIG. **2**. A similar bottom hole assembly is described in U.S. Pat. No. 7,188,685. In this example, bottom hole assembly **22** combines both point-the-bit and push-the-bit technologies. It should be noted, however, the pressurized oil system **24** may be combined with a variety of other types of steerable bottom hole assemblies for use in directional drilling. For example, the rotary steerable system **28** may be a purely point-the-bit system or a purely push-the-bit system.

In the example illustrated, bottom hole assembly **22** comprises an upper stabilizer **58** mounted on a collar **60** which may be positioned adjacent rotary steerable system **28**. A lower stabilizer **62** is attached to an upper section **64** of rotary steerable system **28**. A steering section **65** is connected to drill bit **26**. A surface control system **66** may be utilized to communicate steering commands to electronics in upper section **64**. In some embodiments, the rotary steerable system **28** rotates with the pistons/actuators **34** and the stabilizers **58** and/or **62** may comprise non-rotating stabilizers.

The drill bit **26** is tilted about a swivel **67** which may be in the form of a universal joint **68**. In this embodiment, the steering section **65** is selectively actuated (e.g. pivoted/rotated) about swivel **67** with respect to upper section **64** to actively maintain a bit axis **69** pointing in a particular direction while the bottom hole assembly is rotated at a desired rotational speed of the drill string. Pistons **34** act on a periphery of the steering section **65** to apply a force for tilting the drill bit **26** with respect to the bottom hole assembly or tool axis **38**. The direction or orientation of the drill bit **26** broadly defines the direction of borehole formation. In a push-the-bit type system, the pistons **34** can be configured to act against the surrounding wellbore wall.

In one example, pistons **34** are sequentially actuated by virtue of the pressurized oil from oil system **24** as steering section **65** pivots/rotates. This enables the desired tilt of the drill bit **26** to be actively maintained to ensure drilling in a desired direction through the formation. In other embodiments and situations, the pistons **34** may be intermittently actuated in a random manner by the pressurized oil supplied through oil supply lines **36** to, for example, drill straight ahead as discussed above. In still other embodiments and situations, the pressurized oil from oil system **24** is used to actuate pistons **34** in a directionally-weighted semi-random manner to provide for less aggressive steering as the steering section **65** pivots/rotates. In some situations, the pressurized oil system **24** may be used to activate either all or none of the pistons **34** simultaneously to lock the steering sleeve, e.g. steering section **65**, in a drill ahead configuration and/or to reduce wear on the steering actuators. A variety of methods may be employed to measure the sleeve angle so as to improve control over the toolface and to improve control over the direction in which the sleeve is oriented. As described above, the steering may be achieved by synchronously modulating the pistons **34** in both force and displacement in phase relationship with the desired toolface pointing direction. Accordingly, the pressurized oil system **24** provides great flexibility for controlling directional drilling in a variety of applications and with many types of bottom hole assemblies **22** and rotary steerable systems **28**.

Although only a few embodiments of the present invention have been described in detail above, those of ordinary skill in the art will readily appreciate that many modifications are possible without materially departing from the teachings of this invention. Accordingly, such modifications are intended to be included within the scope of this invention as defined in the claims.

What is claimed is:

1. A system for drilling a borehole, comprising:

a drill bit;

a rotary steerable drilling system to which the drill bit is coupled in a bottom hole assembly, the rotary steerable drilling system being configured to receive a flowing drilling mud and comprising a mechanism for rotating the drill bit to drill the borehole, the rotary steerable drilling system also having a piston actuated mechanism which rotates with the rotary steerable drilling system and which selectively controls at least one of the directional bias or the axial orientation of the drill bit;

a turbine powered independently of the mechanism for rotating the drill bit, the turbine being powered by the flowing drilling mud; and

a pressurized oil system connected to the piston actuated mechanism, the pressurized oil system providing pressurized oil to pistons in the piston actuated mechanism, wherein the pressurized oil system comprises an oil pump driven by a shaft which, in turn, is driven by the turbine powered via the flowing drilling mud, the pressurized oil system further comprising an internal pressure relief valve positioned to maintain a constant pump pressure.

2. The system is recited in claim **1**, wherein the rotary steerable drilling system comprises a swivel.

3. The system is recited in claim **1**, wherein the rotary steerable drilling system comprises a lower stabilizer.

4. The system is recited in claim **1**, wherein the flow of oil from the oil pump to the piston actuated mechanism is controlled by a valve system.

5. The system as recited in claim **4**, wherein the valve system comprises a plurality of bistable actuators.

6. A method of drilling a borehole, comprising:

rotating a drill bit with a mechanism of a rotary steerable system which rotates a plurality of actuator pistons about the borehole;

delivering a flowing drilling mud through the rotary steerable system;

using at least a portion of the flowing drilling mud to power a turbine independently of said mechanism;

adjusting the orientation of the rotary steerable system and thus the drill bit with pressurized oil supplied to the rotary steerable system via an oil pump driven by the turbine;

drilling a directional borehole in a desired orientation as a result of adjusting the orientation of the rotary steerable system with pressurized oil delivered to the rotary steerable system separately from the flowing drilling mud used during drilling, the pressurized oil being delivered to sequentially actuate selected actuator pistons of the plurality of actuator pistons during rotation of the plurality of actuator pistons; and

maintaining a constant pressure on the pressurized oil.

7. The method as recited in claim **6**, further comprising controlling flow of oil to the plurality of actuator pistons by a valve system.

8. The method as recited in claim **6**, further comprising providing the rotary steerable system with a stabilizer.

9. A method of drilling a wellbore, comprising:

conveying a rotary steerable system downhole with a mud motor;

delivering drilling fluid down through the mud motor and the rotary steerable system to remove cuttings;

using a component of the rotary steerable system for rotating a drill bit;

steering the rotary steerable system with a pressurized oil system separated from the drilling fluid, wherein steering comprises pressurizing the pressurized oil with an oil pump located downhole;

controlling the steering by selectively delivering the pressurized oil to actuator pistons which are rotated about the wellbore by the rotary steerable system;

driving the oil pump with an electric motor located downhole, the electric motor being operated independently of the component of the rotary steerable system used for rotating the drill bit; and

maintaining a constant oil pump pressure with a speed control system controlling the electric motor.

10. The method as recited in claim **9**, further comprising modulating actuator piston displacement and forces in synchronism with the phase of drill string rotation to achieve intermediate steering curvatures.

11. The method as recited in claim **9**, wherein steering is achieved by synchronously modulating the actuator pistons in force and displacement in phase relationship with the desired toolface orientation.

* * * * *